Factors influencing the adoption of Software Defined Networking by Research and Educational Networks

Emergent Research Forum (ERF)

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Abstract

Software Defined Networking (SDN) can deliver many benefits to Research and Educational Networks (RENs) and the educational institutions they serve. However, there is limited adoption by the RENs. This paper presents a theoretical model for investigating the SDN adoption by RENs based on the Diffusion of Innovation Theory (DOI) and emphasizes the Technology, Organization, and Environment (TOE) framework. Both theories are widely used in Information Systems adoption research studies at a firm level. The construct components of the study derived from prior literature are 1) Environment (technology support, regulation policies), 2) SDN Technology (advantages, compatibility, complexity, testability, security, observability), 3) Organization (REN size, REN global scope, network user profile), and 4) Human Factor (opinionated leaders, team skills). The model can be used for creating a survey instrument for further researching the adoption process of the SDN paradigm among public and private organizations.

Keywords: Software Defined Network, Adoption, Research and Education Networks, Technology

Introduction

An ongoing effort to meet the demands for real-time large data transfers is the development and implementation of Software Defined Networking (SDN) for better provisioning needs for scientific users (Ibarra et al. 2015). The legacy way of providing service by the telecommunication industry is by deploying proprietary physical equipment (server, switch, router, etc.) for each function of the service, which enables long product life cycles, but low service agility and heavy dependence on specialized hardware (Mijumbi et al. 2016). As data rates from the users continue to increase, the network service providers have to buy and operate new physical equipment, employ operating technicians, and deal with the new rapidly changing skills demands. The legacy way creates high operating and capital expenses. SDN paradigm offers vertical separation of the network's control logic from the underlying routers and switches, promoting (logical) centralization of network control, and introducing network programmability (Kreutz et al. 2015). The goal of SDN is to separate control (using a centralized controller distinct from switches) and data planes (network switches become simple forwarding devices). Research and Educational Networks (RENs) are non-commercial network providers who support research and educational institutions. Adoption of SDN paradigm is slow, despite the suggested benefits of improved efficiency (Xia et al. 2015). SDN can and does deliver many benefits to RENs, however, there is limited research on how RENs are adopting SDN. The motivation of this study is to further research the factors influencing the SDN adoption by the RENs. The study focusses on answering what is promoting/blocking the adoption of SDN in REN.

Theoretical foundation, constructs, and theoretical model

The underlying theories used to create our model are the Diffusion of Innovation Theory (DOI) (Rogers 1962) and the Technology, Organization, and Environment (TOE) framework (Tornatzky et al. 1990). The factors influencing the rate of adoption of SDN by RENs, extrapolated from the literature review, are the Human Factor (Leader's opinion, Team Skills), Organization (REN size, REN Global Scope, Network User's profiles), SDN Technology (Advantages, Complexity, Testability, Security, Observability), and Environment (Technology support, Regulation policies). Rogers' (1962) DOI conceptual model contains five stages of the innovation decision process: knowledge, persuasion, decision, implementation, and confirmation. In this study, the focus is the persuasion stage and the perceived characteristics of the innovation which according to Rogers (1962) are: *relative advantage, compatibility, trialability, observability, and complexity*. The TOE framework identifies three constructs that influence the adoption of a technological innovation: *environmental, technological, and organizational context* (Tornatzky and Fleischer 1990, pp. 152–154). To research the rate of SDN adoption in the RENs *environment*, we will employ the technology support infrastructure and regulations factors affecting the SDN adoption. SDN technology advantage (Jain et al. 2013), compatibility (Ibarra et al. 2015), complexity (McKeown et al. 2008; Yu et al. 2010), testability (trialability) (Jain et al. 2013), security (Dabbagh et al. 2015), and observability (Horvath et al. 2015) are important *technology* factors influencing the SDN adoption. In the TOE framework, the organizational context is referred as descriptive measures such as formal and informal linking structures, communication process, firm size, global scope, and slack resources (Tornatzky et al. 1990).

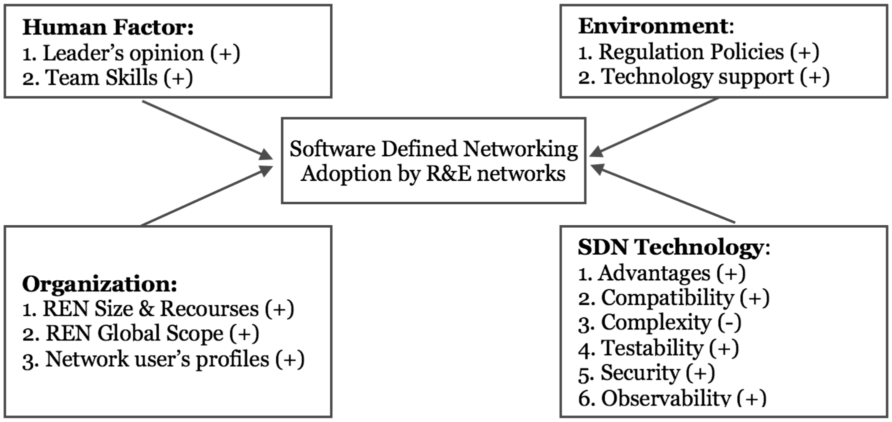

Figure 1. A theoretical model for the adoption of SDN by RENs

To investigate how the *organization'*s factors are influencing the adoption of the SDN by RENs, this research will focus on the firm size, RENs global scope, and the characteristics of the network user's profiles specific to the RENs operations. To emphasize the importance of the human factor, we detach it as a separate construct. According to Rogers (1962), the *human factor* is influencing the diffusion of innovation with the leaders' attitude towards the new technologies, and the team's ability to manage the project. To research the relationship between the constructs human factor and the adoption of SDN by RENs, we will focus on the influence of the "opinionated leaders" (Becker 1970; Fitzgerald et al. 2002) and the team skills (Cosgrove 2016). Grounded in the literature review context discussed above, the conceptual model on Figure 1 was created to research the factors affecting the adoption of SDN in RENs. In the proposed model, the constructs are the *Environment, the SDN Technology, the Organization, and the Human Factor* as shown in Figure 1. In the next section, we are presenting each construct components of the model derived from prior literature.

Environment: Regulation Policies and Technology Vendor support

Networks are typically built from a large number of network devices. Some RENs are spanning across multiple countries (e.g., GÉANT/Europe and RedCLARA/Latin America). In the legacy network the organization's management, performance troubleshooting, and tuning are very complex, lengthily, and error-prone. The network operators are responsible for transforming manually many high level-policies(the path a flow should take) into low-level configuration commands while adapting to changing network conditions (Nunes et al. 2014). Application-Aware Networks and Identity-Aware Networks are examples of high level regulation SDN policies (Polčák et al. 2016). Theoretically, by implementing SDN in RENs, a *policy-based management* framework can be applied at a single controller (Chung et al. 2015). This is especially important when organizations have to share big-data globally. The core of SDN paradigm is to have an open and programmable interface that allows the direct control of some engines, like routing and forwarding, without requiring any in-between adaptation layers, like generic objects to vendor-specific command line interfaces (CLIs). *Vendor support* for open SDN interface is extremely important. Therefore, we propose that:

P1a. The more policy requirements the REN has, the more the organization is prone to adopt SDN.
P1b. The vendor support for SDN capability has a positive effect on the rate of adoption of SDN in RENs.

SDN Technology: Advantages, Compatibility, Complexity, Testability, Security, and Observability

SDN enables the programmability of the network (Boucadair and Jacquenet 2014) and can transform the legacy static network into a platform capable of responding rapidly to changes. Some of the substantial *advantages* from SDN are centralized management and control of network devices from multiple vendors, using APIs to improve automation and management by abstracting the underlying networking details, deliver new network capabilities and services without configuring devices one by one or wait for vendor releases (ONF 2012). In 2011, Google, Facebook, Yahoo, Microsoft, Verizon, and Deutsche Telekom funded the Open Flow Foundation (ONF) to promote standardizing OpenFlow protocol and SDN related novelties. However, replacing a legacy network with new SDN *compatible* equipment is expensive, and a slow migration in a form a hybrid network to a new SDN paradigm could be a solution (Ibarra et al. 2015). In the legacy network, there are a variety of network protocols providing the numerous functions which result in greater *technology complexity*. For a network operator to move or add a device on the network, they have to consider the network topology, a vendor switch model, and a software version. In addition to that, they have to touch multiple switches, routers, firewalls, etc. and update ACLs, VLANs, quality of services (QoS) policies, and other protocol-based mechanisms using device-level management tools. This complexity in the current legacy networks renders the network relatively static as operators try to minimize the risk of service disruption. In an SDN architecture, the logic is centralized in the SDN controller which oversees the global view of the network. The rest of the devices no longer need to understand the many various protocols but accept the instructions only from the SDN controller and the network appears as a single, logical switch. All planes (application, control, forwarding, management), apps and services need to be *tested* in a controlled environment before applied to SDN production environment (Bezerra and Marcos 2016). Currently, SDN tools are mostly based on open source (OFTest, Ryu Switch Test, Cbench). Legacy troubleshooting tools (Ping, traceroute, SNMP, Wireshark, tcpdump) may be partially useful or completely useless. The SDN controller function is the brain of the network and controls where data is going. There is a substantial amount of research on the technical side of the *security* in SDN (e.g., controller as single point of failure), but very limited to how this is affecting the SDN adoption. In 2011, Google led a successful deployment of SDN connecting their data centers (Jain et al. 2013). In 2016 IHS Markit SDN strategy survey, 28 international service providers covering 53% of world's telecom capex, stated that they are currently deploying or planning to deploy SDN in their networks. AT&T, Level3, Colt, Orange Business Systems, SK Telekom, and Telefónica are among the leading adopters (Howard 2016). Other leading companies promoting SDN solutions globally include Big Switch, Juniper, Dell, HP, Cisco Systems, IBM, VMware, NEC corps, and Extreme Networks. SDN is implemented on a national and international level in REN organizations such as Internet2 (Lipscomb 2015), ESNet (Inder Monga 2012), GÉANT (Roberts 2014), AmLight (Ibarra et al. 2015), and AARNet (Hoang 2015). The academic RENs are *observing* the development through workshops and conferences yearly. Therefore, we propose that:

P2a. A higher level of perceived relative advantages of SDN has a positive effect on its adoption by RENs.
P2b. Compatibility with existing legacy networks increases the rate of adoption of SDN by RENs.
P2c. High complexity network technology negatively affects the SDN adoption by RENs.
P2d. The more SDN components are tested before implementation in production, the higher the rate of SDN adoption.
P2e. High level of security in SDN positively affects the rate of adoption by RENs.
P2f. The more visible the results of SDN are, the more likely to be adopted by RENs.

Organization: REN Global Scope, REN Size & Resources, and User Network profile

An organization adopts the SDN according to its needs and requirements. It expects lower operating costs by implementing SDN, automating most network operations and reducing coordination efforts between network operators (Ibarra et al. 2015). The RENs *global scope* consists of connecting varieties of laboratories, schools, archives, and scientific instruments as Laser Interferometer Gravitational-Wave Observatory (LIGO) (Abramovici et al. 1992) and the Large Hadron Collider in Geneva/Swiss (Del Rosso 2012). As scientific instruments produce more big data distributed to different global data archives, a more robust inter and intra REN architecture is needed. Firm *size* is an important characteristic of innovation diffusion, and large organizations facilitate innovation because they tend to have more resources (Rogers 1995). RENs usually are publicly funded not-for-profit organizations that support their operation on collaborations and grants. Upgrading to SDN network equipment and personnel training throughout the network could be very costly. A small *size* REN may not have spare *resources* to implement SDN. SDN on-demand capabilities can dynamically invoke network and storage resources, and operate dynamically adaptive networks according to events and triggers (Boucadair and Jacquenet 2014). The *user's network profile* can be used in multiple areas (capacity planning, analysis, and network security). Traffic patterns can be defined based on the user traffic profiles' segregation of application usage data. This behavior can be utilized for real-time workload characterization and network management (Bakhshi 2017). QoS and allocating recourses can be provided dynamically in real-time by calculating the anticipated traffic, the number of connected users, and network operations. Therefore, we propose that:

P3a. A high number of big-data institutions connected via RENs positively affects the adoption of SDN.
P3b. The size of the REN positively affects the adoption of the SDN.
P3c. The more complex the user's network profiles are, the more the REN is inclined to adopt the SDN.

Human factor: Opinionated Leaders and Team Skills

According to Rogers (1962), the “Early Adopters” are the *opinion leaders*, having the resources and the risk tolerance to try new things. They embrace change comfortably and are already aware of the need to implement new ideas. They need little information (know-how and summary information) about the innovation, acquire it from their local or social network and connections, and test multiple ideas at the same time (Berwick 2003). A successful SDN teams requires a strong foundation of vendor-neutral *knowledge and skills* in both telecommunication engineering and programming. Network engineers are focused on network operations and have limited experience in software development. In addition, they may not be inclined to learn new programming and software development skills, and programmers may not be interested in diving into network configurations. Therefore, we propose that:

P4a. The more positive the leader's attitude towards innovation is, the greater the probability that the REN will adopt SDN.
P4b. Combined programming and networking skills positively affects the adoption of the SDN by RENs.

Conclusion

The factors influencing the adoption of the SDN by REN can be taken into consideration by emerging market economies in countries considering interconnecting their educational institutions. To meet new demands, the RENs are looking into implementation of SDN for provisioning needs for the scientific users. In the proposed model, the constructs to influence the adoption of the SDN by RENs are the Environment, the SDN Technology, the Organization, and the Human Factor. Future research can empirically validate the model by creating a research survey instrument and investigate the current state of the SDN adoption.

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